Why are there so many Spotted-tailed Quolls *Dasyurus maculatus* in parts of north-eastern New South Wales?

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ABSTRACT

This paper explores the question of why the endangered Spotted-tailed Quoll *Dasyurus maculatus* remains abundant in parts of north-eastern New South Wales, while populations in many other areas have declined or disappeared. Based on a two-year field study of a high-density population, we discuss a number of possible explanations for this pattern. These include high availability of prey (in particular, arboreal mammals), quality and spatial extent of habitat, low density of competitors, and relatively small home range sizes of females compared to those in other areas.

We emphasise the importance of maintaining high densities of hollow-bearing trees, which probably help to support prey populations. Managers should also seek to maintain an abundance of fallen timber, which provides shelter and movement pathways for quolls.

We hypothesise that the low density of foxes in our study area, along with the large expanse of relatively undisturbed habitat, most likely explains the high abundance of *D. maculatus*. However, experiments are required. Fox removal experiments should be conducted as a matter of highest priority, and should seek to measure the response of quolls to the removal of foxes at least at the individual level and preferably also at the population level.

Key words: Quoll, *Dasyurus*, Red Fox, competition, forestry, predator removal experiments

Introduction

The Spotted-tailed Quoll *Dasyurus maculatus* is a partly-arboreal marsupial carnivore with a highly fragmented distribution in eastern Australia (Jones *et al.* 2001). The species is listed as endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act* (1999), and threats include destruction of habitat, climate change, the possible impacts of introduced predators and possible non-target effects of programmes aimed at controlling introduced predators (Mansergh 1983; Maxwell *et al.* 1996; Long and Nelson 2004; but see also Glen *et al.* 2007b). Despite the decline in abundance and distribution of Spotted-tailed Quolls since European settlement in Australia (Settle 1978; Caughley 1980; Dickman and Read 1992), localised areas remain in north-eastern New South Wales where the species persists in abundance. We studied a population of Spotted-tailed Quolls in Marengo and Chaelundi State Forests (30º 07'S, 152º 23'E), approximately 40 km north-west of Dorrigo in northern New South Wales. Elevation in the study area ranges from 900 - 1300 m, and mean annual rainfall is 1600 - 2000 mm. The area is covered predominantly by open, dry sclerophyll forest, and common canopy species include *Eucalyptus campanulata*, *E. laevopinea*, *E. nova-anglica* and *E. nobilis*. Temperate rainforest typically covers gullies and creek lines. In the centre of the study site is a cleared area of private leasehold land (approximately 4 km^2) on which cattle are grazed. A more detailed description of the study site can be found in Glen and Dickman (2006a,b).

We investigated the dynamics of the Spotted-tailed Quoll population using mark-recapture techniques (Glen 2008), described the diet using scat analysis (Glen and Dickman 2006a), and studied the home ranges, denning behaviour and microhabitat use of quolls using radio-telemetry and spool-and-line tracking (Glen and Dickman 2006b). Finally, we investigated evidence for interactions between sympatric quolls and eutherian predators, such as overlap in resource use, and evidence of direct interference (Glen and Dickman 2008).

Sixty individual quolls were trapped over 22 months (Glen 2008). Körtner *et al.* (2003, 2004) also reported high local abundances of *D. maculatus* in their study sites in north-eastern New South Wales. This high abundance affords the opportunity to investigate the ecology and life history of the species in detail, but also provokes an important question: why are Spotted-tailed Quolls still abundant in these areas, while populations elsewhere have declined or disappeared? The answers to this question will be vital to ensure the conservation and recovery of Spotted-

tailed Quolls, and the information gleaned during our study provides a number of possible explanations. These include the high availability of prey, the quality and spatial extent of habitat, low densities of Red Foxes *Vulpes vulpes*, and small home ranges of female quolls in comparison to those reported from many other parts of New South Wales and Victoria. We will discuss each of these possible explanations in turn. Our aim is not to reach definitive conclusions, but to generate hypotheses and recommend priorities for future management and research.

Availability of prey

Glen and Dickman (2006a) found that Spotted-tailed Quolls in Marengo and Chaelundi State Forests took mammalian prey as a high proportion of the diet. Medium-sized mammals constituted the bulk of the diet, and Greater Gliders *Petauroides volans* in particular were a staple, occurring in over 25% of quoll scats. Greater Gliders were frequently seen during the course of the study, and their high abundance was confirmed by a spotlight survey in the same forest in which over 40 Greater Gliders were recorded along a single 1-km transect (Forests New South Wales unpublished data). The high abundance of Greater Gliders in the study area suggests that the retention of hollow trees during forestry operations is effective in maintaining large populations of these and other species of obligate hollow-nesting mammals. The importance of gliders in the diet of quolls emphasises the value of forestry practices that actively seek to maintain the abundance of common species, as well as to protect threatened species.

The importance of arboreal mammals such as Greater Gliders in the diet of quolls is probably due not only to their abundance, but also to the fact that other mammalian predators, which lack the climbing ability of *D. maculatus*, are less effective at exploiting this prey resource. Thus, it is not only the abundance, but the *availability* of prey that is likely to be important. The availability of prey is determined not only by their abundance, but also by their accessibility, distribution and level of vigilance, which in turn are influenced by predators (Brown *et al.* 1999). Although other medium-sized mammals (e.g. European Rabbits *Oryctolagus cuniculus*) were also abundant in the study area, quolls did not eat these at such high frequency as they did Greater Gliders. Rabbits were heavily preyed upon by foxes and Wild Dogs *Canis lupus* ssp. (Glen and Dickman 2008), and this may have reduced their availability to quolls. Greater Gliders, on the other hand, were consumed infrequently by other mammalian predators, and may therefore have been more readily available to quolls. Similarly, Belcher (2004) emphasised the importance of arboreal prey in allowing niche separation between quolls and introduced predators.

This apparent reliance by quolls on Greater Gliders raises the possibility of competition between quolls and Powerful Owls *Ninox strenua*. Predation by Powerful Owls can greatly reduce the local abundance of Greater Gliders (Kavanagh 1988). Although Powerful Owls were heard calling during this study (A. Glen pers. obs.), it is not known whether they were abundant in the area.

On a regional scale, north-eastern New South Wales is an area of exceptionally high biodiversity (Burbidge 1960; Pressey *et al.* 1996; Ferrier *et al.* 2000, 2002). This fact may also contribute to the abundance and diversity of prey for Spotted-tailed Quolls at our study site. However, we do not believe that this alone can account for the high abundance of quolls. In searching for study sites, we surveyed many other areas in north-eastern New South Wales where quolls were not present at detectable densities (A. Glen unpublished data). Additional explanatory variables must therefore be investigated.

Quality and spatial extent of habitat

Due to a number of its biotic and abiotic features, we believe that our study area may represent high quality habitat for *D. maculatus*. Spotted-tailed Quolls prefer forests at high elevation on productive soils (Catling *et al.* 2002), and such areas may also be preferred by arboreal prey species (Braithwaite *et al.* 1984). Furthermore, an abundance of fallen timber contributes to the structural complexity of the habitat in Marengo and Chaelundi State Forests, and provides many potential den sites. Quolls were also shown to use fallen logs extensively when travelling (Glen and Dickman 2006b), as was the case for Spotted-tailed Quolls in Tasmania (Jones and Barmuta 2000). Similarly, rocky outcrops have been identified in previous studies of Spotted-tailed (Belcher 2000), Western *D. geoffroii* (Morris 2000) and Northern Quolls *D. hallucatus* (Oakwood 1997; 2002) as potentially important sources of shelter for denning and/or refuge from predators. Structurally complex granite outcrops are common in Marengo and Chaelundi State Forests, and throughout much of the tablelands of north-eastern New South Wales. These may further enhance the quality of habitat for *D. maculatus*. A high abundance of hollow trees in the present study site (A. Glen pers. obs.) may also contribute to the quality of the habitat by supporting high densities of hollow-nesting prey, and by providing plentiful den sites for *D. maculatus*.

In addition to habitat quality, the spatial extent of habitat in the study region is likely to be important. Spotted-tailed Quolls occupy large home ranges, and females appear to have exclusive territories (Belcher and Darrant 2004; Claridge *et al.* 2005; Glen and Dickman 2006b). By definition, such a social system demands large areas of habitat in order to support a viable population. Based on the sizes of female territories (Belcher and Darrant 2004; Claridge *et al.* 2005; Glen and Dickman 2006b), areas in the order of hundreds of square kilometres are likely needed to support enough females for a viable population. Populations in smaller fragments would be vulnerable to extinction through inbreeding, genetic drift or stochastic events, unless immigration occurred periodically from other populations (e.g. Soulé 1980).

Marengo and Chaelundi State Forests form part of a large, continuous expanse of native forest, which encompasses several other state forests, national parks and nature reserves, spanning over 100 km from north to south. Although it is not known whether the density of quolls is consistently high throughout this entire area, it is

likely, at the very least, that this large expanse of forested habitat readily allows dispersal of quolls from one area to another. Connectivity of habitat on a large spatial scale is vital to the long-term survival of many species and to the function of ecosystems (Soulé *et al.* 2004; Hobbs 2005). The relative ease of dispersal in this landscape probably moderates the impacts of localised disturbances such as fire. As well as buffering populations from the impacts of stochastic events, migration is also important in minimising inbreeding and genetic drift (Soulé 1980).

The large expanse of forested habitat in north-eastern New South Wales also means that much of the available habitat is protected from edge effects (e.g. Harris 1988; Dijak and Thompson 2000). In particular, foxes are absent from, or occur at low densities in many forested areas in eastern New South Wales separated by more than about 2 km from freehold land (Catling and Burt 1995). As discussed in the following section, the low density of competitors such as foxes may be an important factor contributing to the abundance of Spotted-tailed Quolls in Marengo and Chaelundi State Forests.

Density of competitors

Competition from other carnivores may threaten the persistence of the Spotted-tailed Quoll, with the impacts of foxes likely to be of particular concern (Long and Nelson 2004). However, the relative densities of competitors can have profound implications for the outcome of competition (Vázquez *et al.* 2007). Foxes, Feral Cats *Felis catus* and Wild Dogs were all recorded in Marengo and Chaelundi State Forests during the course of our study (Glen 2005; Glen and Dickman 2008). Quantitative estimates of their abundance were not attempted, however a concurrent study by Forests New South Wales and the Department of Environment and Conservation (DEC) NSW, now the Department of Environment, Climate Change and Water (DECCW) (unpublished data) monitored the abundance of predators in the study area using an index derived from tracks on sand plots. Foxes were shown to occur at very low density. This is supported by the results of Catling and Burt (1995), who found no evidence of foxes in Chaelundi State Forest, and by our own observations. Foxes were sighted rarely during the present study, and only one individual was captured, despite extensive trapping effort. Wild Dogs and Feral Cats, on the other hand, were more frequently seen (Glen 2005; Glen and Dickman 2008), and much more frequently recorded on sand plots (Forests NSW, DEC unpublished data). Population viability analysis (Burnett and Marsh 2004; Glen 2005) has shown that quoll populations may be sensitive to exploitation or interference competition from eutherian carnivores, while the combined effects of both are likely to have drastic effects on a population's probability of survival.

Foxes, Wild Dogs and Feral Cats are all likely to compete with *D. maculatus*, both through exploitation and interference. However, we believe for a number of reasons that foxes are more likely to compete strongly with *D. maculatus* than are Feral Cats or Wild Dogs. Firstly, Red Foxes have a strong propensity for interspecific killing (Palomares and Caro 1999; Körtner *et al.* 2004; Glen and Dickman 2005). Secondly, there is a high degree of dietary overlap between foxes and quolls [Pianka's index of overlap = 0.712 (Glen and Dickman 2008)]. Thirdly, by virtue of their smaller home ranges (Saunders *et al.* 1995; Meek and Saunders 2000), foxes can exist at much higher densities than Wild Dogs.

Although Feral Cats can also exist at high densities (e.g. Denny *et al.* 2002), they are unlikely to compete as strongly with quolls as do canids, because cats consume smaller prey on average (e.g. Jones and Coman 1981; Catling 1988; Molsher *et al.* 1999), and may not be dominant over Spotted-tailed Quolls in aggressive encounters (e.g. Le Souef and Burrell 1926). Furthermore, the apparently low density of foxes in parts of north-eastern New South Wales contrasts strongly with their density in other areas (Catling and Burt 1995) where Spotted-tailed Quolls have declined (Lunney and Leary 1988; Maxwell *et al.* 1996; Belcher 2004). Thus, the rarity of foxes in Marengo and Chaelundi State Forests may be a major factor contributing to the abundance of quolls. The relatively high numbers of Wild Dogs in the area may further suppress the abundance of foxes, thereby protecting quolls through an indirect commensal relationship (Glen and Dickman 2005; Glen *et al.* 2007a; Johnson *et al.* 2007). Future research should aim to test this speculation.

Home range size

Spotted-tailed Quolls in Marengo State Forest appear to occupy smaller home ranges than those described in southern New South Wales and Victoria. For example, the estimated mean home range size of female quolls in our study area (Glen and Dickman 2006b) was around 20 - 50% of the estimates obtained by Belcher and Darrant (2004) and Claridge *et al.* (2005) (Table 1). Although mean home range size may have been underestimated in our study, this is unlikely to account for a difference of such magnitude. If female home ranges are indeed smaller in north-eastern New South Wales, this may allow higher densities of *D. maculatus* to exist. In turn, small home ranges may be a consequence of a highly productive landscape with abundant resources such as prey and den sites.

Table 1. Estimated home range areas (minimum convex polygon) of female Spotted-tailed Quolls *Dasyurus maculatus* in northern and southern New South Wales and Victoria.

Site	Mean Home Range ± s.d. (ha)
Northern NSW	
Marengo (Glen and Dickman 2006b)	133 ± 45
Southern NSW	
Badja (Belcher and Darrant 2004)	596 ± 487
Tallaganda (Belcher and Darrant 2004)	380 ± 247
Kosciuszko (Claridge *et al.* 2005)	244 ± 72
Victoria	
Suggan Buggan (Belcher and Darrant 2004)	613 ± 406

Management implications

Our studies in Marengo and Chaelundi State Forests have a number of implications for the management of forestry operations in areas where Spotted-tailed Quolls occur. Firstly, the importance of maintaining (or increasing) densities of hollow-bearing trees must be emphasised. Tree hollows are important to quolls as a source of both shelter and prey. The importance of hollow-bearing trees is recognised by Forests New South Wales (e.g. Williams 2001). In north-eastern New South Wales, a minimum of five hollow-bearing trees (and five mature 'recruit' trees) must be retained for every hectare harvested, and this figure is increased to eight where high densities of Greater Gliders occur (IFOA 1999). This additional prescription for Greater Gliders is primarily intended to maintain the prey base for large forest owls such as the Powerful Owl, but is also likely to benefit populations of *D. maculatus*. It is possible, however, that Powerful Owls may compete with and/or prey upon Spotted-tailed Quolls, which could potentially negate any such benefit.

The frequent use by quolls of fallen logs as den sites and as a means of travel (Glen and Dickman 2006b) shows that these may be an important structural feature of the habitat. Fallen timber is abundant in Marengo and Chaelundi State Forests, largely due to the forestry practice of leaving timber off-cuts *in situ*. This practice should continue, and be introduced in any areas where it is not currently applied.

During the course of the present study, selective logging was conducted within the trapping area, and quolls continued to be trapped in close proximity to these operations (Glen 2005). In addition, much of the trapping area had been subject to harvesting less than two years prior to the commencement of this study (Forests NSW unpublished data), and continued to support high densities of quolls. This demonstrates that quoll populations can persist in areas subject to selective logging. However, clear-felling has been implicated in local declines of Spotted-tailed Quolls in Victoria (Belcher 2004). It is imperative that forestry operations be managed in a way that seeks to minimise disturbance. The maintenance of prey populations and structural habitat features is likely to be of greatest importance.

Future research

Our studies have demonstrated that there is considerable potential for competition to occur between Spotted-tailed Quolls and foxes (Glen 2005; Glen and Dickman 2008). However, conclusive evidence may be gained only from fox removal experiments. There are two possible approaches to such experiments: 1) to monitor the response of quolls to the removal of eutherian carnivores at the population level, and 2) to monitor the short-term response of individual quolls to the removal of other carnivores. Theoretically, the first approach is preferable because it is populations, rather than individuals, that are of most concern in conservation (McIlroy 1982; Soulé 1985; Caughley and Sinclair 1994). However, such an approach may be logistically difficult because it would require several replicated areas that support high densities of both quolls and potential competitors. We are unaware of any such areas. Indeed, if competition is strong, then such areas are unlikely to exist except perhaps for transient periods when food and other resources are very abundant. Removing eutherian carnivores from areas where they are already scarce is unlikely to have a measurable effect on quoll populations, while monitoring in areas of low quoll density would yield hopelessly small sample sizes for many years before a detectable increase might be expected (Glen 2005). In Western Australia, for example, low density populations of the Western Quoll averaged a five fold increase over a period of eight years (Morris *et al.* 2003).

The second approach would focus on individual quolls whose home ranges are known to overlap with those of eutherian predators. By collecting detailed information on such individuals, responses to predator management may be detected. For example, individuals may expand or shift their home range, or make more frequent use of certain microhabitats or resource patches following removal of eutherian predators. Detection of such responses would require very accurate monitoring with fine spatial and temporal resolution. Emerging technologies such as satellite (e.g. Ballard *et al.* 1998), GPS (e.g. Frair *et al.* 2004; Lewis *et al.* 2007) and contact telemetry (e.g. Sirtrack 2005) are most likely to provide useful insights, particularly as new equipment approaches a size and weight that may be fitted to quolls. Individual responses such as these may be more quickly and readily detectable than population-level responses, and would provide a strong indication that populations are likely to respond to ongoing predator management. Confirmation that behavioural responses at the level of the individual often translate to population-level shifts has been obtained for several species, such as Snowshoe Hares *Lepus americanus* (Hik 1995) and House Mice *Mus domesticus* (Dickman 1992; Arthur *et al.* 2004, 2005).

Conclusions

The Spotted-tailed Quoll remains abundant in areas of north-eastern New South Wales, despite having declined dramatically across much of its geographical range. The principal factors that are believed to have caused the species' decline either do not apply in these areas of abundance, or their effects have been more moderate. These factors include clearing and alteration of habitat, habitat fragmentation, and the effects of eutherian predators. These threats may also act synergistically. For example, the impacts of eutherian predators are often exacerbated by habitat fragmentation (Long and Nelson 2004). The area in which this study was conducted forms part of a large expanse of forested habitat, and is therefore relatively unaffected by the first two of these factors. However, eutherian predators are present in the area and, in the case of Feral Cats and Wild Dogs, are relatively abundant. Foxes, on the other hand, are scarce. We hypothesise that the low density of foxes in our study area, along with the large expanse of relatively undisturbed habitat, most likely explains the high abundance of *D. maculatus*.

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APPENDIX I

A female Spotted-tailed quoll shortly after being released from a cage trap.

Photo, A. Glen

A radio-collared quoll regards her trackers from the safety of her den.

Photo, A. Glen

The thin thread of a tracking spool reveals the entrance to a quoll den in a hollow log.

Photo, A. Glen

Volunteer Dean Portelli braves a chilly dawn on the Marengo Plain to radio track a quoll.

PhotoA. Glen

APPENDIX I

A Spotted-tailed quoll inside a cage trap.

Photo, A. Glen

A female clambers along a fallen log after being released from a cage trap

Photo, A. Glen

A basal tree hollow inside which a radio-collared quoll could be seen resting.

Photo, A. Glen.